A New Technique for Troubleshooting Large Capacity Energy Storage Banks

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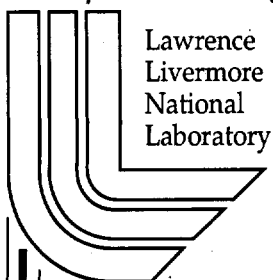
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A new technique for troubleshooting large capacitive energy storage banks[*]

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Introduction

The Power Conditioning System (PCS) of the National Ignition Facility (NIF) like many pulse power systems relies on large numbers of inductively isolated high voltage capacitors configured in parallel for energy storage. When an energy storage capacitor fails in such a capacitor bank, there is often little or no external indication showing which capacitor failed. Identifying the failed component can be a time consuming and potentially hazardous operation. Conventional methods using capacitance meters require that each capacitor be disconnected and tested independently. We have developed a new non-invasive technique (i.e. no dismantling of the bank is required) that greatly improves personnel safety as well reducing troubleshooting time.

Theory of Operation

A simplified schematic diagram of the National Ignition Facility (NIF) Main Energy Storage Module (MESM) is presented below. The actual bank consists of up to 24 capacitors and their attending damping
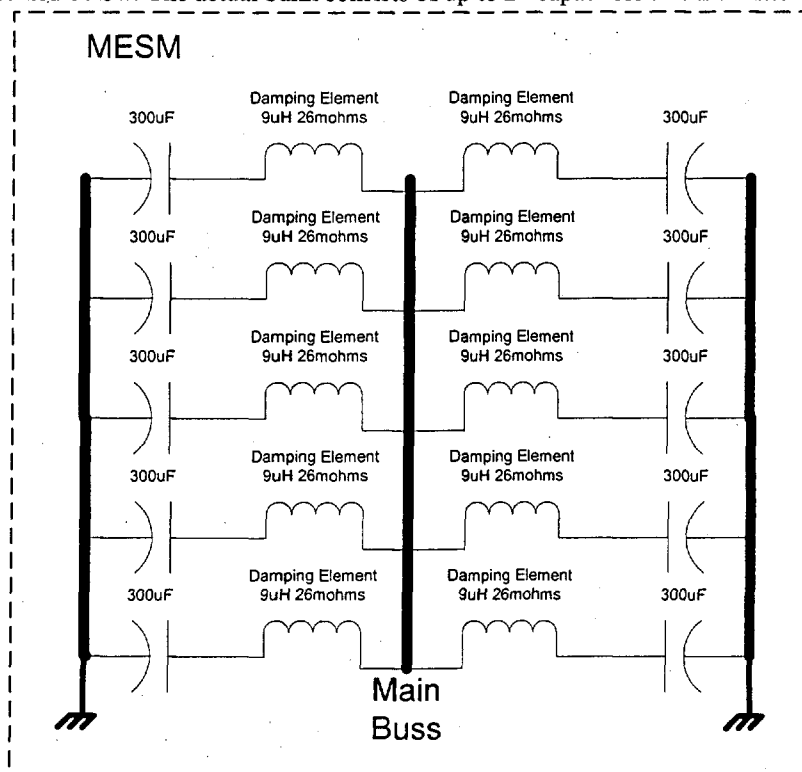
element. Each individual capacitor can store up to 100kJ. This could of course be any large inductively isolated capacitor bank.

If an AC signal is introduced across any single capacitor the circuit may be re-arranged to produce the equivalent circuit shown below:
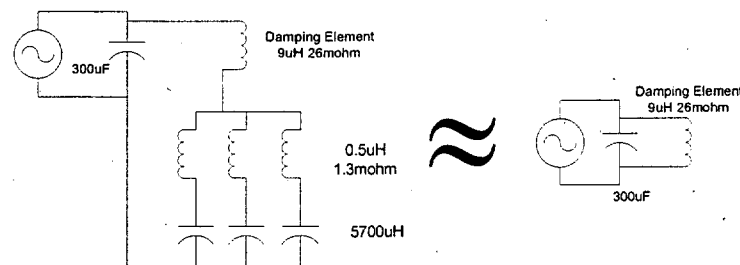

We are now left with a very simple parallel resonant pair, or in radio terms a "tank" circuit. Recalling basic circuit theory, we recognize that impedance for a parallel LC circuit is highest at the resonant frequency. If we make the source a sweep generator we can find the resonant frequency of our tank circuit by watching for either a peak in the voltage across the capacitor or a null in the current supplied by the generator. In the case of the NIF bank the resonant frequency turns out to be very close to 3kHz. All of the individual circuits (capacitors) should look pretty much the same with the exception of the circuit with the bad capacitor, which will either not resonate at all (most likely) or will resonate at a significantly different frequency from the rest.

Description of Hardware

The equipment is battery powered and is not referenced to building ground, providing an extra measure of safety for personnel and equipment. Initial proof-of-principle tests were done with AC powered equipment with known good capacitors to which small additional capacitors were added or taken away.
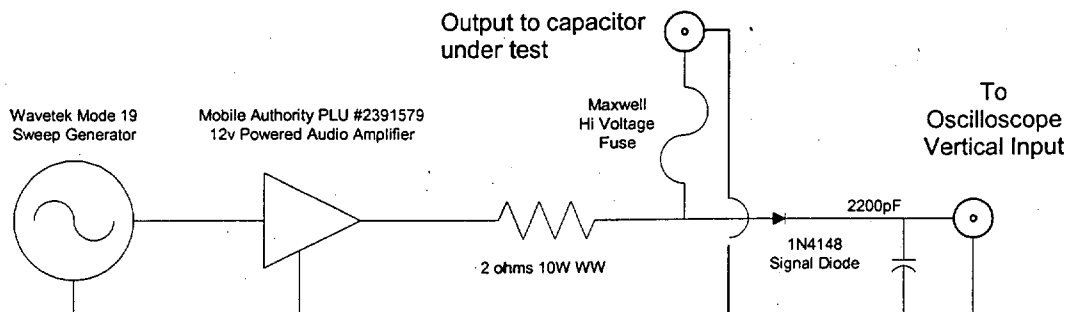
The basic circuit diagram of the tester is shown above. The sweep generator is an AC powered unit but requires only a few watts. Power for this unit was provided by an inexpensive 12VDC to 120VAC inverter. The amplifier was required to improve the signal to noise ratio. The impedance of the circuit at resonance is less than one ohm. As noted above the primary frequency for the NIF is 3kHz very conveniently located in the audio band. A automotive stereo amplifier was selected as battery powered, robust and inexpensive. The two-ohm series resistor provides a stable load for the amplifier. The output of the amplifier is coupled though a large high voltage fuse. Connection to the capacitor under test is through a length of RG-58 co-axial cable mounted to the end of 8 foot insulating pole. The signal diode and capacitor form a simple

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** The Titan Corporation acquired the pulsed power portion of Maxwell Physics International Company in March, 2001, after the completion of the project described in this paper

Amplitude Modulated (AM) detector for ease of display and interpretation. A battery powered digital oscilloscope rounds out the system.

Test Results

Two oscilloscope traces from actual capacitor measurements in a NIF MESM are shown to the right. The top waveform shows the response of a normal NIF capacitor/damping element pair. Note that the resonant frequency is slightly above 3kHz, as the hand calculation would predict. The lower trace shows a different capacitor (200μF) with the same inductor. The resonant frequency has shifted to about 3.7kHz as expected. Changes as small as 30μF can be easily detected (tested by adding and removing a 30μF capacitor in parallel with the unit under test.) However the differences in inductance of the ground return for each capacitor can also account for this much variation. To reliably detect such small changes, the return lead of the probe must always be connected to the same point on the module frame.and the data compared to measurements made when the bank is in a known good condition.

Techniques of Operation

All normal precautions for dealing with a potentially lethal capacitor bank must first be observed. The bank must be discharged and checked for any dielectric memory voltage. The central bus should be grounded for additional electrical safety, but this is not required for the operation of the equipment. A small low voltage/low current "reference pair" of a 300μF capacitor and a 9μH inductor is placed across the output leads of the test probe. The start frequency of the sweep generator is set to 2kHz, the stop to 4kHz. The sweep rate is adjusted until a signal sweep just fills the screen. Similarly, the vertical scale of the oscilloscope is adjusted to provide a full-screen signal. The reference pair is removed and the return lead of the probe is attached to the can of the capacitor under test. The test probe is applied to the junction of the capacitor and it's associated inductor. The resonant frequency is noted and compared to other capacitors in the bank.

A flat line at the bottom of the trace indicates a shorted capacitor, no trace (voltage off scale high) indicates an open. Resonant frequencies above 3kHz indicate a partial loss of capacitance in the unit under test. Frequencies below 3kHz indicate a very unlikely increase in capacitance; if this occurs, the tester should again be tested against the reference pair to confirm proper operation.

Future Plans
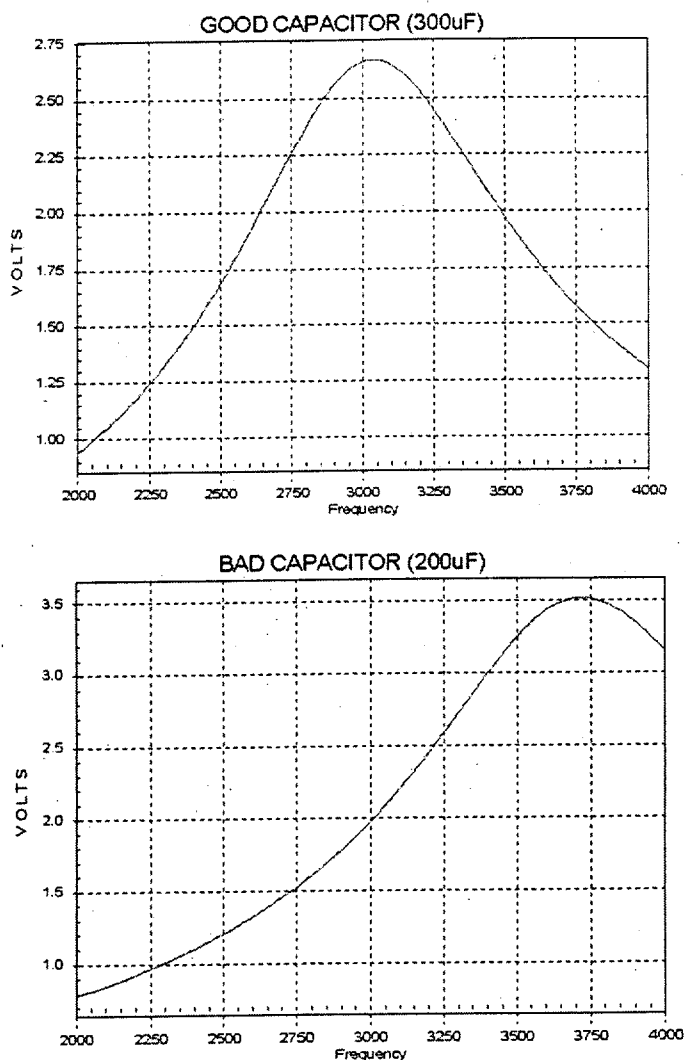
One disadvantage of the current system is that physical contact must still be made to inject the signal into the junction of the inductor and capacitor. One proposed improvement is to drive a coil with the output of the amplifier and inductively couple the signal via transformer action into the damping element of the capacitor under test. In effect we would build a 3kHz "Grid Dip Meter" another piece of technology borrowed from the RF world.

Finally, using a laptop computer to replace both the sweep generator and the oscilloscope will enhance the whole system. A PCMCIA data acquisition card will provide both D/A and A/D functions. The D/A function will create the sweep frequency signal that will still be fed to the amplifier. The A/D section will record the voltage at each frequency. There are many advantages to this approach: A laptop computer is less expensive than an oscilloscope. It is inherently battery powered. The sweep signal generator and its DC/DC inverter are eliminated. The system will be more compact and transportable. Finally, record keeping will be simplified. The characteristic resonance for each capacitor/inductor pair could be quickly measured and stored in a spreadsheet or database. In the event of failure, overlaying the original data with the current measurement can provide an easy and quick go/no go test.

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